

Engineering in the Ocean: Loads, Environment, and Structural Behaviour

Devesh Kumar

Transcript

13th May, 2026

Devesh Kumar. "Engineering in the Ocean: Loads, Environment, and Structural Behaviour." 13th May, 2026. <https://www.xkdr.org/viewpoints/engineering-in-the-ocean-loads-environment-and-structural-behaviour>

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Introduction to offshore engineering

- [00:00:00] **Devesh Kumar:** Good evening everyone. Uh, so in this seminar, I will be talking about the offshore engineering as Ajay Shah mentioned. So I will be taking the engineering perspective on the offshore engineering. And I will be using
- [00:14:00] **Audience Member 1:** [inaudible]
- [00:16:00] **Devesh Kumar:** Yeah, I will be using offshore wind turbine as a primary example. But, you know, the fundamentals, the underlying principles are same for all the structures. So here I will be talking about how we do the statistical analysis of the random waves, uh, how we obtain the loads. So it is same for, be it a oil and gas platform, or other subsea structures like pipelines or, uh, cables, or you have an other energy systems like, uh, these days wave energy converter is getting popular, or we have this floating solar also.
- [00:16:00] **Devesh Kumar:** So I will be talking about that.
- [00:53:00] **Devesh Kumar:** Uh, so when most of the people who are not from the engineering background, when they see any offshore structure, they see what is visible, what is above the water. But from the engineering perspective, uh, we are seeing as at a complex dynamic system. When I see dynamic system, uh, any structure in the ocean is exposed to a time varying load. So you have loads like wind, waves, and these are not constant loads.
- [00:53:00] **Devesh Kumar:** Every moment it is changing. So that is what I mean by dynamic.
- [01:27:00] **Devesh Kumar:** And unlike other civil structures which we, which we build on the lands, uh, offshore systems are never at rest. Like the environment is constantly acting them through a time varying load. Also, uh, in this, in this talk as, uh, I, when I was talking to Ajay Shah, he was telling that some of you are from, like, many of you are from the economics background. So from the engineering perspective, I will try to, uh, build a background like how we connect the engineering concept into it.

- [01:27:00] **Devesh Kumar:** So you, even if your background is not engineering, you can still appreciate how the mathematics or physics or structural mechanics come together to develop any offshore system.
- [02:14:00] **Devesh Kumar:** Uh, yeah, so here I have given a broad, um, bird view of the whole talk. You can say it is the agenda of the talk. So this seminar I have divided into two components. First is the offshore system, and the second is the physics behind the system.
- [02:14:00] **Devesh Kumar:** So we will begin with understanding the difference between a offshore and onshore, what are the complexities with the offshore wind resources. At the same time, we will also discuss even despite of all those challenges, uh, we should still consider a offshore wind farm because I will show you how it is better than onshore wind.
- [02:51:00] **Devesh Kumar:** After that, once we have established that, we will, I will show you a general arrangement of a offshore wind farm. Here I have taken Dogger Bank as a case study, uh, because it is one of the largest, uh, wind farm we have, like it is 3.6 gigawatt wind farm in, uh, it is supplying electricity to UK. So that we will see. And then once after that, we will take one of the wind farm and then we will see different components of wind farm.
- [02:51:00] **Devesh Kumar:** Once that part is over, then we will see the physics behind it, like how we analyze the marine environment, how we calculate the loads, and then we will try to, uh, like when we will, we will try to chain together all the things, uh, and then we will see like each steps, how we are arriving at the final design of the offshore.
- [03:50:00] **Devesh Kumar:** Uh, also in case you have any questions or doubt, you can, uh, please feel free to, uh, ask me in between also. So, uh, yeah. So, in this slide, uh, I will show you what is the difference between onshore and offshore. So at very, uh, superficial level, both systems may look similar.
- [03:50:00] **Devesh Kumar:** Like both have towers, blades, generators, but structurally, uh, or even environmentally, they are entirely different engineering problem.

- [04:20:00] **Devesh Kumar:** Uh, for onshore wind, the primary environmental load is, uh, obviously wind. Uh, the structures are, when, when you install onshore structure, onshore wind farm, the, the ground which we are installing it, it is relatively stable. The foundation systems are very straightforward. Uh, even though the wind is dynamic in nature, like you will have a mean wind speed.
- [04:20:00] **Devesh Kumar:** Let's say you have a wind speed of 10 meter per second and, but it will keep on changing, let's say 9.5 to 11.5, whatever. So it will keep on changing. So even though it is dynamic in nature, but still the, uh, environment in onshore is quite predictable.
- [05:01:00] **Devesh Kumar:** However, uh, when we talk about a offshore wind, it introduces, we call it a multi-hazard. Like we have wind, we have wave, we have current. Even the seabed is not constant because, you know, the current is flowing and then it is keep on changing the seabed. We call it like a iscowering.
- [05:01:00] **Devesh Kumar:** Like you put something in the ocean and then when current is passing, it will, uh, it will, uh, take some of the sediments with it. So it is, it is also changing.
- [05:30:00] **Devesh Kumar:** And here we have like we we should not focus just upon a, you know, one type of dominant wave or one, sorry, one type of a dominant load. We have to solve a coupled, uh, like we have to solve a coupled dynamics. What I mean by coupled is basically suppose when wave is hitting a structure, so it is moving the structure. At the same time, wind is also hitting a structure.
- [05:30:00] **Devesh Kumar:** So there is a aerodynamic load and due to this wave and since the structure is moving, it will feed back into the aerodynamic loading. So it is not, it is not like independent of each other. Everything is acting together.
- [06:06:00] **Devesh Kumar:** So we have we have to solve the coupled equations. Uh, so that also slightly complicate things. Uh, then, uh, as I said, seabed is not perfectly known. The ocean conditions are stochastic.

[06:06:00] Devesh Kumar:

What I mean is in layman terms, stochastic is basically random. Uh, also the seabed environment is quite harsh, so corrosion is a big problem. And it is like constantly it will degrade the materials, so we have to provide protections for the corrosion. And one of the important thing is the fatigue which becomes many times it becomes a design consideration.

[06:42:00] Devesh Kumar:

So in land, like, okay, some of the components are exposed to the fatigue, but in offshore, it is a very important thing you have to see because millions of small, small waves that are hitting the structure, it will like even a small wave can do small damage. And fatigue is basically, uh, due to cyclic load, uh, even though like it is basically accumulation of all those small, small waves. So we have to consider that also.

[07:09:00] Devesh Kumar:

And the biggest challenge like many people thinks, as I said, many people thinks that, okay, we have, once we know that we have designed something for, let's say, a maximum possible wave that can occur, uh, but in reality, we have to see the maximum possible wave or wind that can hit the structure as well as we have to see the even the smaller millions of waves that can hit the structure. So we have to design for the both, both the things. Uh, so here in this slide, the main thing what I'm trying to say is, uh, I wanted to show that offshore structure is highly complex when you compare it with the onshore. And now I will show you in the next slide that even with all those complexity, we should still move toward offshore.

Why offshore wind

[08:05:00] Devesh Kumar:

Yeah, so this is, this is a data from a magazine called Future Winds. Uh, so you can see if, let me zoom in. Uh, yeah. So, you can see, uh, that, uh, in offshore, the wind, like, here they have like, it is, uh, in this, in this, uh, they have, did this, uh, test, like basically measured the, uh, wind speed at different heights.

- [08:05:00] **Devesh Kumar:** It is from, I think it is one of, from the China, some China Sea, but the trend is same across everything, uh, every other ocean environment also that we get higher, higher wind speed at same height in the wind in in the ocean.
- [08:51:00] **Devesh Kumar:** So, uh, in offshore, the wind is like, uh, the, the wind is more consistent. It is stronger and it is less turbulent. So what happens is when you have this, uh, stronger wind and less, like, there is a less turbulence, then it improves the capacity factor. If I give you some numbers, so, uh, in the offsho, in the onshore, the capacity factor is around 25% and in offshore it is around 40 to 50%.
- [08:51:00] **Devesh Kumar:** For those who are not aware of the capacity factor, let me give you an example. Suppose you are building a one gigawatt, uh, wind farm.
- [09:29:00] **Devesh Kumar:** Uh, so if capacity factor is let's say 50%, that means that on an average it will give 0.5 gigawatt. Uh, so it is almost for the offshore it is almost twice. The the second advantage is the space. Like offshore wind farms require enormous area.
- [09:29:00] **Devesh Kumar:** I will show you in the Dogger Bank, like they, it is like it was done in three steps, like Dogger Bank A, B and C. Each is around 500 square kilometers. So it requires a enormous area. And building such projects creates challenges like, you know, land acquisition or environmental restrictions.
- [10:09:00] **Devesh Kumar:** Like you can't cut down trees to, just cut down trees to put the, uh, offshore wind. It's kind of negate the, you know, uh, the benefit like we are talking about green energy and then we are cutting down trees. So it requires large areas. Also there are social acceptance.
- [10:09:00] **Devesh Kumar:** Like these wind turbines are, let me zoom out. Yeah. These wind turbines are quite noisy, so you have to build it somewhere like far from the city. So if you see at all those things, when we talk about off, offshore, it is quite far from the society.
- [10:43:00] **Devesh Kumar:** Uh, we have this something called like huge space. We can build on that. Also, one more important thing is the transportation. Like suppose you have to build a like you have to build a big turbine.

- [10:43:00] **Devesh Kumar:** Let's say 15 megawatt wind big, uh, turbines. The blade size is around 120 meters or 115 meters. So transporting it through road is quite complicated in on in offshore, onshore. However, in offshore, we have these specialized vessels which can carry, uh, these very easily.
- [11:15:00] **Devesh Kumar:** Also, the buoyancy helps in transportation. Uh, I mean, when, let's say you have to transport any steel tube or any component, so when you put it in the water, its weight reduces. Sometimes we attach these floating, uh, boys which provides extra buoyancy and then we will what we will do is we will tow it. Like it will just float on the surface and we will tow it to the location.
- [11:15:00] **Devesh Kumar:** So even the transportation becomes, uh, quite, uh, easy.
- [11:45:00] **Devesh Kumar:** So these are the consideration. So these are the consideration we have to see that we can build very large wind, uh, wind farm at one place that is possible with the offshore and we have stronger winds. So based on these things, we can say that offshore wind is even though with all those complexities, uh, it is far better than the onshore.
- [12:12:00] **Devesh Kumar:** Any question till now?
- [12:15:00] **Audience Member 1:** Uh, what about like, uh, is it on?
- [12:20:00] **Devesh Kumar:** Yes.
- [12:21:00] **Audience Member 1:** Yeah, uh, it is on. So, what about risks? Like for instance, if we have a black swan event like a hurricane, like major hurricane, uh, and then it the offshore, would it damage and would it be significant or are they damage proof now? Or is it expensive to make it damage proof?
- [12:47:00] **Devesh Kumar:** It's not damage proof, but while doing the engineering analysis, we have to like, suppose in India especially, it is a cyclone zone. So we have to pass that, uh, like we have to, we have to calculate what is the damage. Is that damage is under the acceptable limit? For example, let's say there is a, uh, one thing I was talking about the fatigue.

- [12:47:00] **Devesh Kumar:** So we have to make sure that fatigue should not cross certain limit. We call it 10% .1, it should not cross the factor of .1. So we calculate those things as well when we are designing any or we are deploying any system. So we need to calculate for that.
- [12:47:00] **Devesh Kumar:** Obviously it will cause damage, even the waves and everything is causing damage, but it should be under the limits.
- [13:35:00] **Audience Member 2:** So, um, Devesh, I'm sure researchers have thought about this, but I would be curious that, uh, you will recall there was a great tsunami that hit the coast of Tamil Nadu. It would be interesting to simulate conventional designs for that particular shock. Ayush, would that address your question?
- [13:57:00] **Audience Member 1:** I think just from a finance perspective, if you have like 100 billion dollars there and, you know, one black swan event like a 400 KPH cyclone, which can happen just before the shore, right? And it destroyed everything, then it's risky from a finance, overall finance perspective, or a tsunami for that matter.
- [14:15:00] **Audience Member 2:** Yeah, so, uh, if you have a lot of money spread over 500 square kilometers, but if there's a single shock that hits all the turbines, then it's an undiversified, large, lumpy investment. So this would be curious as to your thoughts that, uh, are we designing for these kinds of events? That in, are we designing for 25 years? And so then what kind of extreme event in the 25 years are we designing for?
- [14:43:00] **Devesh Kumar:** Yeah, so usually when we are going for 25 years, we take this 100-year return period, all kind of, uh, all types of possible event that can happen in that location in 100 years. So we have to design for all those things. So, uh, yeah, obviously, we have to design for even the like suppose it is, it is very slightly far away from the, from far away from the coast, then we can go for a structure, like different types of, I will go come to this type of substructure which we design.

- [15:14:00] **Devesh Kumar:** So we can go for something called floating type of a sub-structure. Uh, so what happens is, um, you might have heard this like when tsunami, if tsunami comes, it damage just the coast part. If it is some floating body is in the, in the, in the water, it will just float, like I mean, it will not observe the shock. It will, it will just the shock will just pass through it.
- [15:14:00] **Devesh Kumar:** Also, if there is a monopile, we must have to design for that as well. So we have to consider it.
- [15:42:00] **Audience Member 3:** Devesh, uh, can I, uh, this is Manish here. Um, just a, uh, zoomed out question. Um, my understanding could be dated, but, uh, the problem today with wind even with onshore is, uh, transmission, the bottle means a lot of the engineering on the blade and the stuff is far ahead of the problems that we have on the transmission side. Is is that correct still?
- [16:12:00] **Devesh Kumar:** Yeah, so transmitting, like the grid problem is something different. So, but the transmitting that like whatever is the wind energy which we are generating, so if we have to transmit that from the wind energy to the, let's say onshore grid, so that is you can resolve by, uh, like these days we have these DC cables which are like power loss is very less, 4 to 5%. Uh, power loss we see in 1000 kilometers. So, uh, the transmission I, like, I feel it is resolved when you, when you take, let's say, whatever is win, whatever, um, the wind farm is generating, we can transmit it to the land.
- [16:12:00] **Devesh Kumar:** But again, uh, land grid, how it is, it is, uh, another question.
- [16:58:00] **Audience Member 3:** No, but, but the, but the problem is still in the, uh, it creates intermittency on the grid, right? Also there's two problems. One is the transmission costs, and second is the intermittency that it creates on the grid. Right now, the, if I, if I understand correctly, and this is maybe my, it's only mostly on the India side.
- [16:58:00] **Audience Member 3:** Uh, the issues are mostly to do with the, uh, grid. Grid is the bottleneck rather than the every, anything else. Is that, is that fair to say or not correct?

[17:31:00] **Devesh Kumar:** Uh, yeah, I, I don't have a proper answer on that, the grid part of India. Uh, yeah, but, uh, if we see like most of the projects which I have done, it is in the European reason and it is quite successful. So I think it it should be resolved here as well. So I have not studied properly the grid in Indian context.

[17:55:00] **Audience Member 3:** So, so, fair enough. Thank you.

[18:00:00] **Devesh Kumar:** So, should we move ahead?

[18:03:00] **Audience Member 2:** Yeah.

Anatomy of an offshore wind farm

[18:05:00] **Devesh Kumar:** Yeah. So, now we have established one thing that how offshore wind is better. So now I want to show you a general arrangement of how offshore wind, uh, offshore wind farm look like. So here, let me take a leisure.

[18:05:00] **Devesh Kumar:** So, yeah, so we will have these wind, lot of wind turbines which will be connected through the inter-array cable. Uh, and then these and these are basically, these will generate power in in AC and this will go into this substation, which is basically, uh, it is where the conversion of AC into DC happens. The reason is, as I said that the power loss of DC cable is quite less.

[18:51:00] **Devesh Kumar:** So, uh, this DC cable will again go to the, uh, grid and then it will connect to the, basically the onshore grid. Here I have taken an example of Dogger Bank. Uh, so it was done in three phase, A, B and C. Uh, A and B was deployed two years back and then C was I think last year.

[18:51:00] **Devesh Kumar:** So it is overall 3.6 gigawatt of wind it is generating. So general arrangement I have shown you here. So we have used this 13 megawatt, uh, wind turbines in A and B and in C we used uh, 14 megawatt.

- [19:31:00] **Devesh Kumar:** And just to give those people who have like, uh, less idea about these gigawatt numbers, what is mean by this 3.6. So suppose, uh, I just took an example like suppose, uh, you have this capacity factor is, uh, we have seen that it is 40 to 50% for the offshore wind. So on an average, it will generate, uh, 1.62 gigawatt. So if you convert that into what is annually we are producing and then you will divide it by the average power consumption.
- [19:31:00] **Devesh Kumar:** Let's say it is, let's say we are consuming some 250 units per month, uh, then it will be around, it will give electricity to almost five million houses.
- [20:13:00] **Devesh Kumar:** Uh, in terms of Chennai, it is like, overall population is seven million. So number of houses, uh, will be obviously two or four people are living in single house. So it will be giving electricity to large population. So yeah, I think give coming to your previous question, I think if the, like, this was deployed in UK and it is successfully giving electricity, so I hope the grid problem, uh, the transmission problem, transmission is not a problem in this case.
- [20:13:00] **Devesh Kumar:** Grid can be one.
- [20:47:00] **Devesh Kumar:** So yeah, overall area if I talk about, the overall area is around 500 to 600 square kilometers for each phase. And then water depth was around 50 to 60.
- [21:05:00] **Devesh Kumar:** Yeah, here I have shown you a general arrangement of a wind turbine. So we you have this, uh, you have this, on the top, you have this, uh, we call it RNA, uh, rotor nacelle assembly. So basically this this blade will rotate and then you have this gear system which will increase the RPM and then in the end you will have generators which will create the electricity. But in this talk, I will focus more on the foundation which supports the whole tower because this is something, uh, you know, this is something which is, uh, different from the offshore, from the onshore because it is something which is exposed to the marine environment.

- [21:43:00] **Devesh Kumar:** So, uh, when it comes to the substructure, uh, we have basically two types of substructure. One is the fixed and the other one is the floating type. Uh, so the choice of the substructure depends on what is the water depth we are going to install in. Uh, so basically suppose you have a fixed type, it is good for up to 60 meters water depth.
- [21:43:00] **Devesh Kumar:** So let me zoom, sorry. Let me zoom in here. Uh, uh, so you have this monopile. It's, it's kind of a simple pile on which we put the, uh, put the tower.
- [21:43:00] **Devesh Kumar:** Uh, it is good up to 30 meters and it is like, you can say it is mostly, like most of the big projects still, like till today, it is on the monopile.
- [22:26:00] **Devesh Kumar:** Then you have jacket kind of a structure. It is basically, um, it these are, uh, the, like as you can see, these are mostly popular you have seen it in the oil and gas platforms they use. And it is good up to 60 meters. As we go even in the deep waters, then we go towards the floating types.
- [22:26:00] **Devesh Kumar:** Just for the like intuition, it's like a ship and then over the ship you are putting a turbine. In reality, it is not a ship. It is something like this structure.
- [22:56:00] **Devesh Kumar:** The main point is from the physics you can see that when wind is acting on the structure, it will rotate the structure. It will try to rotate or it will try to topple the structure. So we have to, we have to design something which can create a, uh, which can create a, you know, this, uh, restoring moment. If I draw here, yeah, so suppose you have this structure and then when, when wind is hitting, it is trying to rotate this.
- [22:56:00] **Devesh Kumar:** And then you, suppose you have this structure in this ocean.
- [23:33:00] **Devesh Kumar:** So what happens is it will move something like, something like this. Let's say this is our water level. So what happens is I'm just giving one of the examples. So what happens is suppose this this will, this will try to top, this will try to rotate.

[23:33:00] **Devesh Kumar:** Then here the net area is increasing. So it kind of increases the boin, boincy, boyant force. So it will again create a restoring moment. Uh, yeah.

[23:33:00] **Devesh Kumar:** Also there are different mechanism like we have these mooring lines and all. That can also create that is also helpful in creating these restoring moments.

[24:05:00] **Devesh Kumar:** So for this for this for this fixed type we have this Dogger Bank was built on these monopiles and for floating this Highwind Scotland was built on this, we have, uh, it was a semi-submersible was used for this type of structure.

Marine loads and structural dynamics

[24:27:00] **Devesh Kumar:** Yeah. So I will now I will go into the different types of environment and how our, uh, structure response to those, those, basically how these structure respond to those loads, that I will try to explain. Here I have just given a simple, uh, figure that what type of loads that happens. So we have these wind loads, uh, and then we have these, uh, waves that is happening.

[24:27:00] **Devesh Kumar:** And then, uh, current and even the landslide is also happening. So these are the loads which are happening.

[25:00:00] **Devesh Kumar:** Also, there can be, uh, other loads like, um, you know, these, as you said, like due to tsunamis and due to the cyclones, there can be other loads. Those things I have not shown here. But yeah, these are the ways. In this, if I say these are basically dynamic loads.

[25:00:00] **Devesh Kumar:** The wind load, uh, wind load, wave load are dynamic in nature because it is varying with time. So in the next slide, I will show you like how we will deal, how we deal with these dynamic loads.

[25:30:00] **Audience Member 2:** Any question till this point? All good.

- [25:36:00] **Devesh Kumar:** Okay. So, suppose here, now I will come into the engineering side of things. So, basically, suppose this is the wave which is, which is moving in this direction. So when when I am saying here, I have presented a wave with very nice sine curve.
- [25:36:00] **Devesh Kumar:** But in reality, it will not be a sine curve. It will be a very random wave. So what happens is, if you see this, this wave, this wave if, if you see me, sorry, uh, laser.
- [26:05:00] **Devesh Kumar:** Let me show. So if you see this wave which is going like this, uh, on the top, so it is looking like the wave is going from this direction, but in reality, the particle is moving up and down, up and down over here. It's just the energy transfer. So what happens is when this, let's say when the peak is, uh, local maxima is crossing the structure, it will apply load in this direction, and when minima is there, it will apply load in the opposite direction.
- [26:05:00] **Devesh Kumar:** So it's a time varying. So it will at the same time, it will, uh, you know, move the structure or structure will respond, the structural response will be a time varying as well. It will not be a one directional wave. So here I have given two examples.
- [26:48:00] **Devesh Kumar:** One is your monopile, simple monopile and other is your floating type. So same thing is happening. It is the, let's say it is a mean point. It can move in this as well as this direction.
- [26:48:00] **Devesh Kumar:** Uh, here I have just shown you one directional single, uh, in single degree it is moving, but in reality it can move in multiple directions. Uh, so what, let me go to the next slide and I will come back to this. So I, I just want to tell you like what we do in the physics is basically we represent these structures as a simple, let's say, uh, single, this here I have given you example of single, uh, mass spring damper system.
- [27:27:00] **Devesh Kumar:** Mass is basically, like suppose you have to represent, you have to represent this whole wind turbine as this. So this mass is representing the, uh, inertia part. Let's say, let me draw one figure. So suppose this is your, this is your structure and let's say, sorry.

- [27:27:00] **Devesh Kumar:** Suppose this is your structure and this is, this is your mass. So, uh, what is happening is the whole inertia of the system, this mass can come, come due to the, uh, due to the this whole, uh, blades and hub, also the the steel, whole tower part. So this is represented by a mass.
- [28:07:00] **Devesh Kumar:** Spring is basically you can say, um, it is like a stiffness. Stiffness is something which is like when suppose you are trying to rotate something and it is, it is resisting that moment. That is basically represented as a stiffness. And damper is something which is basically all the places where we are, uh, the energy is getting dissipated.
- [28:07:00] **Devesh Kumar:** So all those places, so what what we do is we we simplify this model. I have like totally simplified, but in reality, suppose we will divide all those system into small, small nodes, and then each node will represent a, uh, small spring mass system.
- [28:47:00] **Devesh Kumar:** And then let's let me explain here. So what happens is, suppose you move this, you move this structure in this in this direction. So there will be a force. Uh, there will be a force, uh, due to the like, let's say you have moved this X displacement, so there will be a KX force that will happen.
- [28:47:00] **Devesh Kumar:** So it will, it will oscillate at this position. So if you have to solve this, uh, I have given a simple, you know, from the second law of Newton, you can, you can say that it is basically mass into acceleration, which is force.
- [29:22:00] **Devesh Kumar:** Then kx is the force due to spring, and then damper is like for for damper system, the force is basically proportional to the velocity. So this is a two-degree differential equation which we solve to obtain the, this will give like from this equation we get the response. Response looks something like this. Like suppose it is a mass damper system and you applied some force and you leave it.
- [29:22:00] **Devesh Kumar:** So slowly the energy will get dissipated and it will go to the this point. Now, the whole purpose of this slide was that there are like when suppose there is a natural frequency of this structure and then suppose we are loading the structure at the same frequency.

- [30:03:00] **Devesh Kumar:** What happens is, uh, everybody have heard about the resonance. So resonance will happen and then it the the response will amplify a lot. So we have to make sure here I have shown you something called dynamic amplification. Let's say, let me explain.
- [30:03:00] **Devesh Kumar:** Like suppose if you are hitting a structure with one meter wave and then it is responding let's say two meters. So dynamic amplification is two. So we have to make sure that when we are designing any system, the dynamic amplification should be low. It should not be very high.
- [30:03:00] **Devesh Kumar:** Otherwise amplification will be so high that it can, uh, damage the structure. So what we will do is we avoid any any frequency or, uh, which is like, uh, suppose we are in the field, so we we will do the analysis of the ocean and when we we will find out that what is the frequency of the ocean?
- [31:07:00] **Devesh Kumar:** Uh, let's say, in general, we say that the, the time period of the ocean wave is between 5 second and 20 second. So we will avoid that zone. So we have to make sure whenever we are designing the structure, it should not be in the, uh, in the wave band of the structure. Let me just come back to this slide.
- [31:07:00] **Devesh Kumar:** So this is what I was trying, I am trying to explain over here.
- [31:30:00] **Devesh Kumar:** So there is a energy wave band, uh, that here I have shown that in general it is five second to 20 second which represent a ocean waves. So we have to avoid that zone and then when your blades are moving, it has its own frequency. Like if it is taking one circle, then it has its own frequency and if it is taking, like one, 120 degree, these are three wave blades. So when it is doing this 120 degree rotation, then there is other frequency that we represent by one p and two p.
- [31:30:00] **Devesh Kumar:** So we have to make sure that whatever frequency we are, uh, trying to design, it should not lie in this zone. Otherwise, uh, otherwise this amplification will happen.

[32:17:00] **Audience Member 2:** So just to say, in ways that I'm understanding, you will design the physical structure to have frequencies that are away from the forcing frequencies of the real world so that you don't get to a resonance phenomenon. In a resonance phenomenon, the energy transfer will happen and, uh, our best material science will break down. So our job is to make sure we are at different natural frequencies.

[32:42:00] **Devesh Kumar:** Yes. Yes.

[32:44:00] **Audience Member 4:** How does the load dampener work? What do you mean by a dampener? Is it a separate piece?

[32:49:00] **Devesh Kumar:** Sorry? Dampener, how does the dampener work? Is it a separate piece? Dampener, uh, it is just a representation of all the places where energy is getting dissipated.

[32:49:00] **Devesh Kumar:** Like it can dissipate in the structure. Like the, basically, it's a, uh, it's a, you can say it's, uh, it, it can, the energy loss can happen due to the structure also. When we are embed certain length in the seabed, due to the soil also it is, it is, some of the energy is getting lost. Also at there is a hydrodynamic damping due to the wave, due to the due to the ocean itself, there is certain energy loss.

[32:49:00] **Devesh Kumar:** So the whole thing we are trying to represent as a small figure of dampener.

[33:33:00] **Audience Member 4:** Yeah, fair enough. Thanks. I thought it was a separate piece of.

[33:37:00] **Devesh Kumar:** Sorry? No, no, I thought it was a separate piece. I, fair enough, I got that. Okay, okay.

Measuring and modelling ocean waves

[33:47:00] **Devesh Kumar:** Yeah. So, now coming to the statics. So we understood that we should not model something on near the resonance. So let's see that how we actually analyze the ocean.

- [33:47:00] **Devesh Kumar:** Uh, so this is basically kind of the first step what we do. So, uh, basically, how do engineers know what wave to design for? And when the, like, we know that ocean is different every single moment, every single second it is, it is different. So I have shown you using this very simple, uh, very simple four step loop that the real measurements, uh, basically we do real measurements using these bay, buoys.
- [34:27:00] **Devesh Kumar:** So these wave buoys are present in the ocean. So these are very small buoys. So whenever this, this wave, incident wave happen, like, uh, come to or pass through this buoys, it will just record the, uh, elevation with respect to time. So we will put these buoys for years, um, years in the ocean and then based on that we go to the next step.
- [34:27:00] **Devesh Kumar:** So what we do is, uh, it is recording basically whenever the surface is going up and down, it is recording that. And based on that, we will build a probabilistic model. I will come to the models. Uh, and then the model will basically tell you the statistical behavior of the waves at that location.
- [35:10:00] **Devesh Kumar:** And from the model, we do all the future predictions, uh, that let's say we have to find out next 100-year return period wave. So when I am talking about 100-year return period, I mean that what is the maximum wave that can happen in next 100 years. So these things we have to use, uh, different types of probabilistic models. I have given the names like also, just for those people who are more curious, uh, since I can't cover the given in the time domain, I can't cover all the things.
- [35:10:00] **Devesh Kumar:** So what I have done is, I have created this link additional reading material, which I have created basically a simple Python code which goes through different steps. So I have, I have taken one random wave and then at the end, it goes through all the eight steps and predict the extreme. So those those people who are interested can please check that.
- [36:04:00] **Devesh Kumar:** Uh, so what we do is basically let me walk through the steps. So, what happens is we, we will deploy these sensors. This will extract your crest and trough that basically local maxima and local minima. And then we will count how often these wave reach a reach any certain height.

- [36:04:00] **Devesh Kumar:** That is basically a crossing intensity of that particular wave height. Then what we do is, we convert that irregular sea state into a, uh, into a, something known spectral density function. What we do is, let me zoom in over here.
- [36:42:00] **Devesh Kumar:** So we will, we will have this kind of measured wave records. And, uh, and from this, we do this Fourier analysis. Fourier analysis is basically any, any irregular wave we can, uh, through Fourier analysis, we can represent in terms of the, uh, summation of sine and cosine waves. So here you can see that this irregular wave which is which we will see in reality, this we can represent by summation of hundreds and hundreds of these sine waves.
- [36:42:00] **Devesh Kumar:** And each sine wave has its its different amplitudes. So if you sum it up, you can get this. So what we will do is, uh, based on these amplitudes, like each amplitude and each each, each, each sine wave has its own amplitude and frequency and phase.
- [37:32:00] **Devesh Kumar:** We will represent it as an energy spectrum. So what ener, what energy spectrum tells us, suppose this this is this is our chart in the red line you can see. So what it will show is wherever it is maximum, the top, top most point, it says that, uh, at that particular location, uh, it this particular frequency is, uh, occurring lot of times. So as I said in the previous slide, so from the, so from the, suppose you know that which frequency is occurring a lot, those frequency causes resonance.
- [37:32:00] **Devesh Kumar:** So that thing we must know.
- [38:09:00] **Devesh Kumar:** So basically this is from this, uh, from this you get this spectrum. And then let's say it is, it is coming at point. So in this, can you see my cursor? I hope you can see my cursor or.
- [38:28:00] **Devesh Kumar:** Am I audible?
- [38:34:00] **Audience Member 2:** Yes, you are.
- [38:38:00] **Devesh Kumar:** Yeah. So, I hope my cursor is visible to everybody.

[38:41:00] Audience Member 2: Yes.

[38:43:00] Devesh Kumar: Yeah. So basically, uh, let's say these are the, these are the outliers. Here these are the outliers, but in this is the zone we should avoid. So from this, from like, what what we are doing is from this we are creating this energy spectrum.

[38:43:00] Devesh Kumar: Energy spectrum is basically proportional to square of the amplitude. I hope amplitude is basically wave height, you can say, twice, half of the wave height. So these are the spectrum. So from spectrum we get the relevant data like, uh, we call it a C state.

[38:43:00] Devesh Kumar: When we are designing anything, uh, if you go through many of the papers in from this domain, you you might have, uh, read this this this, sorry, read this term called C state.

[39:28:00] Devesh Kumar: C state is basically for any location, if we have to describe a C at this point, we need minimum of four parameters. That is wave height, time period, uh, direction it is hitting and the water depth. So with that we can get all the other parameters. So, uh, with this spectrum, basically, uh, it's a representation of those.

[39:28:00] Devesh Kumar: So even with very small, let's say one year wave, we can build this spectrum, so that will take, when that will basically tell me the statistical nature of that place and based on that, we can fit, let's say, uh, different types of distributions. So, for example, let's say we have to do the extreme wave, we have to find. So generally we use this generalized extreme value, GEV. So with that we can get, okay, in 100 years, what type of maximum load that can happen on the structure.

[40:27:00] Devesh Kumar: Uh, yeah. Also, yeah, here you can see, I have given some regional table that will give you the sense of a scale. Uh, in North Sea, uh, where, like, uh, it is a place where most of the wind farms are made. That's why I am talking more about the north, that's why I will talk more about the North Sea.

- [40:27:00] **Devesh Kumar:** So basically, uh, here you can see that in one year, the HS or wave height which we are getting is 14 meter. And 100 year it is 22 meter. Just to give an idea, like 14 meter is almost five-floor building it is hitting. So we have to design for that.
- [40:27:00] **Devesh Kumar:** And same thing if you see in the Persian Gulf, it is almost five meter.
- [41:12:00] **Devesh Kumar:** Uh, so even with same physics, every location is having different environment. So, uh, we have to take based on that we have to take the all the structural decisions. Uh, yeah. So yeah, those who are interested, please go through this link, maybe in the end, I will show you this.
- [41:12:00] **Devesh Kumar:** Any, any, any questions on this?
- [41:37:00] **Audience Member 2:** Can I ask if do you have any survivorship issue with the balloons? Like, do you have data for all the balloons or sometimes do you have balloons which are damaged? And how do you do in that case?
- [41:52:00] **Audience Member 3:** So the problem that the meters that experience the worst conditions, something would tend to break and so our data would be biased in favor of looking more tame.
- [42:05:00] **Devesh Kumar:** You mean these boys you're talking about?
- [42:08:00] **Audience Member 3:** The data capture boys.
- [42:12:00] **Devesh Kumar:** Sorry, I didn't get the question. Can you can you please repeat?
- [42:17:00] **Audience Member 3:** Does it happen that the data capture boys work perfectly or does it happen that they fail? If so, could there be a survivorship bias problem? That devices that experienced the most weird conditions are more likely to fail, so our data set is biased in favor of looking more tame.
- [42:39:00] **Devesh Kumar:** Yeah, but usually we put it like it is not like we are putting single boy in the in the field. So we took that redundant, uh, scenario in consideration. There will be multiple boys and we will be getting data from all those.

[42:56:00] **Audience Member 5:** Uh, so can I then just augment this with one? Devesh, uh, with one question, which is, um, in a in a matrix of boys, what is the failure or the loss of the boys in a given matrix? Is that something that we capture?

[43:14:00] **Devesh Kumar:** Uh, uh, yeah, like if some data is like quite looking quite weirdly, uh, uh, yeah, I'm not totally aware of it, to be honest. So, uh, yeah, mostly we should we will be capturing this like we will be we will be putting multiple boys. So some of the boys will be giving, uh, not so good data. But one more thing I want to add, when these these, when you have these floating boys, the when you have these floating structures in the ocean, even if there is a very huge wave which is hitting, it is most likely it, it is not going to fail this.

[43:14:00] **Devesh Kumar:** Like since these are very small and it will just float over the over the elevation. So it doesn't observe most of the, you know, load from the waves.

[44:02:00] **Audience Member 5:** No, I, yeah, agreed. It's just a a question of curiosity and fact, I suppose, which is how many of these boys end up dying and need to be replaced and is there anything that we can learn from the failure of these boys with respect to the accuracy of our data that goes into the models?

[44:22:00] **Devesh Kumar:** No, yeah, this is something I need to explore myself also. I am not very sure on this.

[44:28:00] **Audience Member 5:** Okay, thank you.

[44:33:00] **Devesh Kumar:** Anything, anything else?

[44:37:00] **Audience Member 3:** So we go on?

Calculating loads on offshore structures

- [44:38:00] **Devesh Kumar:** Yeah. So, till now we understood that, uh, we understood the resonance part and then how we obtain the wave properties, uh, what I mean when I say wave properties, I mean the HS, the wave height, the time period, uh, directions and, uh, yeah, those those are the properties. Now from these properties, how should we obtain the loads? Uh, so in this I will try to tell uh this.
- [44:38:00] **Devesh Kumar:** So in reality what happens is we have we can say three methods to obtain that what type of load which is happening.
- [45:27:00] **Devesh Kumar:** First is suppose, let's say we are building some, let's say 100 meter, uh, wind, uh, overall, 100 meter wind turbine with a sub structure, we are building in the ocean. Uh, so what we will do is, we will create a scaled model and we will test that in a something called wave flume. Like wave flume is basically there we generate waves and then, uh, we will put the sensors and we will see that what types of loads are happening and we will. So this is like you can say this is kind of a most accurate way that you are putting actual model and then you are testing it, uh, testing it, uh, in a wave flume.
- [46:06:00] **Devesh Kumar:** Uh, in India also like in in our campus, IIT Madras, there is a, uh, lab where you can test those things. Uh, and for the aerodynamic part, we can test the model in the, uh, wind tunnel test we can do. So this is one of the method. You just put a scaled model.
- [46:06:00] **Devesh Kumar:** Accordingly, you scale everything down. So suppose 10 meters you have to 10 meter wave is hitting. So you have to scale 10 meter as well. And then, uh, you test it.
- [46:06:00] **Devesh Kumar:** Other method is the computational fluid dynamics. So there we solve this Navier-Stokes equation, which is a, which is a non-linear partial differential equation. So we will solve that and then based on that it gives us what types of, uh, loads or pressure distributions which is happening.

- [46:53:00] **Devesh Kumar:** Uh, so firstly, when we are doing this model tests, it is costly. Uh, the other computational fluid dynamics, it is very time consuming. Like even a simple model can take days or sometime weeks. So there there is other method which is called potential flow theory that comes in and that is quite helpful.
- [46:53:00] **Devesh Kumar:** Uh, so what it does is with the we assume certain things. We assume that our fluid is, uh, non-viscous. Our we can't compress it. So we say it is incompressible, and there is no, uh, vortex formations.
- [46:53:00] **Devesh Kumar:** So we say it, it is a irrotational.
- [47:35:00] **Devesh Kumar:** Like if you have to visualize it, visualize this one, you can say, you can think about it like a, let's say you have to analyze a traffic. Uh, so you you are analyzing a traffic and then instead of taking like each and every driver's behavior, we we are seeing a average flow of traffic and then based on that we are designing. It's something like that. Um, so that is something we do.
- [47:35:00] **Devesh Kumar:** And the good thing is, like we can say that we are analyzing, we are doing lot of idealization, but in reality, what we, what we have seen is from the field data and from this potential flow, we get quite accurate results. It's not like very far away from the results.
- [48:16:00] **Devesh Kumar:** Uh, if the we are analyzing, there are certain physical physics problem which is, uh, which if like suppose very, we are just analyzing how the surface level, surface is behaving when structure is hitting. So when we are analyzing surface behavior, then we have to go for the fluid dynamics, computational fluid dynamics. Otherwise, in most of the cases when we are designing something, this works quite fine. So what we have, we do is, let's say we are modeling, let's say, let me put a pen.
- [48:16:00] **Devesh Kumar:** So let's say we are modeling something in this, this is our structure and then let's say this is our wind turbine.

- [48:56:00] **Devesh Kumar:** So when we are modeling it, so what we will do is, we will define a domain, uh, let's say we are modeling something, let's say 10 meter diameter something. So we will take a, let's say 100 meter, 100 by 100 meter domain and then we will apply this, uh, apply this, uh, potential flow theory. The what we will obtain from this is basically the water particle kinematics. Uh, so what I mean by water particle kinematics is, uh, basically by solving this equation, this particular, this this particular equation, we get at different heights in the sea below this, this is let's say mean sea level.
- [49:43:00] **Devesh Kumar:** Whenever we are going down each each level, what is the velocity and acceleration of all the water particles? That is something we are getting from here. Once we have this, uh, or and also we will obviously we are getting the water particle kinematics. We are also getting the pressure distributions.
- [49:43:00] **Devesh Kumar:** So if we have this pressure distributions and water particle kinematics, from that we can obtain all the loads and all the forces that is happening.
- [50:15:00] **Devesh Kumar:** Uh, I hope it is, it is clear or if you have anything, any doubt on this, please let me know. No, no, fully understood.
- [50:30:00] **Devesh Kumar:** Just a moment. Uh, please go ahead. Yeah. So here what I have done is instead of going through all the equations and everything, what I have done is I have kept one document.
- [50:30:00] **Devesh Kumar:** Uh, just let me quickly go through it, just a glimpse. Uh, of this one. So here what I have done is basically for those who want to go in more detail, uh, I hope my screen, this document is visible.
- [51:04:00] **Audience Member 2:** Yes.
- [51:05:00] **Devesh Kumar:** Yeah. So what I have done is I have taken one, like, step by step how we solve this, uh, potential flow and how we obtained the velocity and accelerations from these potential flow, uh, different types of waves which can happen. So there is something called Airy wave, which is like with lot of assumptions. We assume that our wave is a very simple sine wave.

- [51:05:00] **Devesh Kumar:** But in, in reality, it can be something like this or this. So basically different types of waves and how we obtain, sorry, how we are obtaining loads from, uh, loads from these waves. So these things I have discussed here.
- [51:45:00] **Devesh Kumar:** So people who want to go deep, deep into the, you know, um, this, uh, these equations and all, you can please check this one out. But I will, I will try to explain this with this small, uh, small diagram. So, now we have the wave, uh, from the statics. We know the wave height, its period, and we know from the velocity potential, we know the pressure at each depth.
- [51:45:00] **Devesh Kumar:** So the next question is obviously what type of force that can happen on the structure? So the main answer depends on, uh, how big our structure is.
- [52:28:00] **Devesh Kumar:** Uh, for example, so I have given two figures over here. Uh, the above one is a representation of a small, uh, very thin cylindrical, uh, structure. Let's say it's a monopile. And the other is quite large when, when we compare it with the wavelength.
- [52:28:00] **Devesh Kumar:** So if I, uh, let's say if you have a tub of water and you are putting a broom stick, stick, and let's say with hand if you are generating some waves, so this boomstick will not at all get, like this wave will not be disturbed by the boomstick.
- [53:04:00] **Devesh Kumar:** What I mean is, this wave, it is quite large compared to this, uh, this, this structure. It is, um, this, this type of structure we see in the monopile, the type of substructure which we discussed earlier. So what it does is when this wave passes through it, it this wave is not disturbed by it. So when it is not disturbed, the pressure field is not disturbed.
- [53:04:00] **Devesh Kumar:** Uh, so in this equation, in this case, there is something called Morison equation, which is basically summation of drag and inertia. It is very simple, uh, simple method with which we can obtain the loads. So what we do is, if suppose we have this structure, we divide it into small pieces and then at every level, we have we have, uh, velocity and acceleration and then with that we obtained the, uh, we obtained the loads.

- [53:58:00] **Devesh Kumar:** But now suppose, uh, in the same tub you have, let's say a mug and now you are generating. So this mug will what it will do is, uh, it will, uh, block some of the waves or it will reflect some of the waves or when this mug is moving, it will generate some of the waves. So this is not the same scenario. So for this, we use diffraction theory.
- [53:58:00] **Devesh Kumar:** Uh, diffraction theory, it's, it's a type of numerical method, uh, which we use to obtain the load in this scenario. So yeah, in this in the document, I have given, uh, I there are two links.
- [54:36:00] **Devesh Kumar:** One is the theoretical aspect and other is the example. Uh, example is just again a small Python code which calculates these loads. Uh, so please check that. Uh, and if you have anything, if you want to discuss more on this, please let me know.
- [54:36:00] **Devesh Kumar:** I don't want it to go into all the equations. Otherwise, it will take a lot of time.
- [55:04:00] **Audience Member 3:** Yes, please go ahead.

From environmental data to design

- [55:06:00] **Devesh Kumar:** Yeah. So now once we have the, we have the loads, so basically we started with a very simple question that why should we go offshore? Uh, and the answer is also very simple that we have better wind, we have more space, uh, we have, we can fit bigger turbines. But the harder question is that how you will build something that can survive in the middle of ocean for let's say next 25, 30 years?
- [55:06:00] **Devesh Kumar:** So the steps is like we follow that we collect the data, past data. We will a statistical picture of what this ocean will do over the lifetime.

- [55:45:00] **Devesh Kumar:** From that data, we extract the wave particle kinematics using potential flow theory. From that kinematics, we calculate the loads based on how big our structure is and how small we, we we calculate the loads. And once we have these loads, we do the, uh, we do the certification of the structure. We design the structure and we certify it.
- [55:45:00] **Devesh Kumar:** And one more important thing is, like whenever we are designing the structure, we should not, uh, load the structure, like we should not make a structure so that it matches with the natural frequency of the wave or other loads that can happen in the in the ocean. So this is the overall conclusion I wanted to give you.
- [56:31:00] **Devesh Kumar:** Yeah, so this is the link you can go to GitHub link. Anyhow I will share this PPT with, uh, with the team and then this is the link where I have kept all the documents and Python codes. Uh, thank you.

Supplementary Resources

- Kumar, Devesh. “Statistical Wave Modelling.” Interactive HTML notebook. Published May 13, 2026. https://github.com/singhdeveshkr/offshore_wind_talk_XKDR/blob/main/Statistical_Wave_modelling.html.
- Kumar, Devesh. “Morison Load Calculation on Offshore Pile.” Interactive HTML notebook. Published May 13, 2026. https://github.com/singhdeveshkr/offshore_wind_talk_XKDR/blob/main/Wave%20Loads.html.
- Kumar, Devesh. “Ocean Wave Loads: Potential Flow Theory, Morison Equation, Diffraction Method.” Technical note. Published May 13, 2026. https://github.com/singhdeveshkr/offshore_wind_talk_XKDR/blob/main/ocean_wave_loads.pdf.